

## The PHENIX Muon Arms

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## Abstract

The PHENIX Muon Arms detect muons at rapidities of  $|y|=(1.2-2.4)$  and provide a means of studying vector meson production and the Drell-Yan process (via the detection of muon pairs) and heavy quark production, Z and W production at forward rapidities (via the detection of single high- $P_T$  muons). Each muon arm must track and identify muons, providing good rejection of pions and kaons ( $\sim 10^{-3}$ ). In order to accomplish this a radial field magnetic spectrometer was constructed with precision tracking (Muon Tracker) followed by a stack of absorber/low resolution tracking layers (Muon Identifier). The design, construction, testing and expected run parameters of both the muon tracker and the muon identifier are described.

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## 1 Introduction

The PHENIX Muon Arms detect muons at rapidities of approximately  $|y|=(1.2-2.4)$  and provide a means of studying vector meson production and the Drell-Yan process (via the detection of muon pairs) and heavy quark production, Z and W production at forward rapidities (via the detection of single high- $P_T$  muons). Each muon arm must track and identify muons, while providing good rejection of pions and kaons ( $\sim 10^{-3}$ ). In order to accomplish this a radial field magnetic spectrometer was constructed with precision tracking (Muon Tracker) followed by a stack of absorber/low resolution tracking layers (Muon Identifier).

## 2 The Muon Tracker

The Muon Arm Tracker design specifications were driven by the requirements that it be able to 1) allow a clean separation of  $J/\psi$  from  $\psi'$ ,  $\Upsilon(1s)$  from  $\Upsilon(2s,3s)$  and  $\rho/\omega$  from  $\phi$ , 2) provide a large enough signal-to-background and acceptance for vector mesons to be able to do statistically significant physics measure-

ments in less than 1 year of RHIC running, 3) have low enough occupancy to be able to reconstruct tracks efficiently in Central Au-Au events and 4) still perform well in the lower occupancy but higher event rate p-p and p-A physics programs.

The relative mass resolution is approximately given by  $\sigma(M)/M = 6\%/\sqrt{M}$ . This mass resolution enables a clear separation of  $\rho$  and  $\phi$ ,  $J/\psi$  and  $\psi'$ , with an acceptable separation of  $\Upsilon$  and  $\Upsilon'$ . This is consistent with a spacial resolution of 100 microns.

The above design requirements led to a Muon Tracker design which is comprised of three stations of cathode-strip readout tracking chambers mounted inside conical-shaped muon magnets (see Fig. 1), with multiple cathode strip orientations and readout planes in each station. The electronics design specifications were driven by the requirement that the non-stereo cathode planes provide 100  $\mu\text{m}$  resolution measurements of the particle trajectories and that the readout of the system be able to meet the global PHENIX readout requirements. Test-bench measurements from production chambers and electronics combined with simulations of the full muon tracker design show that the tracker should meet the design requirements outlined above.

### 2.1 Mechanical Design

Each of the three stations of cathode strip chambers (CSC) presented

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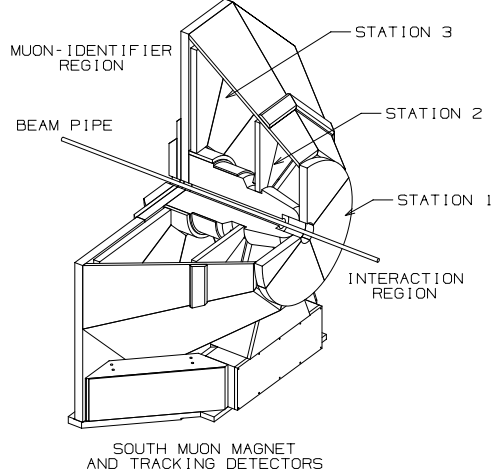


Fig. 1. The South Muon ARM tracking spectrometer. Muons from the intersection region, to the right, intercept the station 1, 2, and 3 detectors and proceed to the muon identifier detectors to the left (not shown).

unique design requirements. All are in the shape of octants electrically, designed with 3.215 mm half gap, 5 mm cathode strips, with alternate strips readout. Honeycomb technology was used for stations 1 and 3 and thin foil technology for station 2. Each station used a specific technology to produce a cathode pattern to an accuracy of better than 25 microns; station 1 used photolithography, station 2 used electro-mechanical etching at a facility designed specifically for this purpose, and station 3 used mechanical routing. A unique wire laying apparatus was designed and implemented for each station. The anode planes are alternating structures of 20  $\mu\text{m}$  gold-plated tungsten sense wires and 75  $\mu\text{m}$  gold-plated Cu-Be field wires with a sense wire spacing of 10 mm. Half of the cathode planes have strips perpendicular to the anode wires and the other half have strips at stereo



Fig. 2. Station 1 is built in four quadrants but is electrically divided into octants to match the octants of station 2 and station 3.

angles between 0 and  $\pm 11.25$  deg with respect to the perpendicular strips. The chamber gas mixture is 50% Ar + 30% CO<sub>2</sub> + 20% CF<sub>4</sub> with a gas recirculation system included in normal operation.

The station 1 tracking chambers are located closest to the interaction region and therefore are the smallest (approximately 1.25m from inside radius to outside radius), have the highest occupancy per strip, and the most stringent requirements on dead regions within the acceptance ( $\geq 95\%$  active area). The chambers are constructed in quadrants using honeycomb panels laminated with photo-etched copper clad FR-4 to produce the cathode strips (see Fig. 2). The quadrant consists of three chamber gaps, each containing a pair of cathode strip planes on either side of an anode wire plane.

Because of the need to maintain good momentum resolution down to 1.5 GeV, the thickness at the station 2 detector was required to be  $\leq 0.1\%$  of a radiation length. To meet this requirement, the station 2 octant



Fig. 3. This octant from Station 2 has six cathode foils and three anode wire planes. The total thickness is  $8.5 \times 10^{-4}$  radiation lengths.

cathodes were made of etched 25 micron copper coated mylar foils. The 6 cathode foils as well as the 3 anode wire planes are made of thin 3.125 mm laminated frames. The station 2 design is a laminated structure of these thin anode and cathode frames held under tension by two thick aluminum support frames. Aluminized mylar windows contain the gas mixture; the three separate CSC detectors are isolated by ground foils. The station 2 octant is shown in Fig. 3; the frame is approximately  $1.9 \times 1.7$  m<sup>2</sup>. The total thickness is  $8.5 \times 10^{-4}$  radiation lengths.

Station 3 chambers are the largest of the tracking chambers with each of the octant chambers about 2.4 m long and 2.4 m wide (Fig. 4). Like station 1, these chambers are constructed using honeycomb panels that are laminated with copper clad FR-4 sheets. The cathode strips are formed by me-



Fig. 4. This octant from station 3 is 2.4 m long and 2.4 m wide and consists of four cathode foils and two anode wire planes.

chanically routing shallow lines in the copper skin. These chambers consist of two gaps, each containing a pair of cathode readout planes on either side of an anode wire plane.

To maintain the momentum resolution, an optical alignment system is installed to calibrate initial placement of the chambers, and to monitor displacements of the chambers to  $\pm 25$   $\mu$ m (Fig. 5). There are seven optical beams surrounding each octant chamber, consisting of an optical fiber light source at station 1, a convex lens at station 2 and a CCD camera at station 3.

## 2.2 Electronics Design

The Muon Tracking Front End Electronics is the interface between the muon chambers and the PHENIX online DAQ system. The electronics continuously amplifies and stores analog hit information from the chamber cathodes. Upon receipt of a level 1 trigger from the PHENIX granule timing module (GTM),

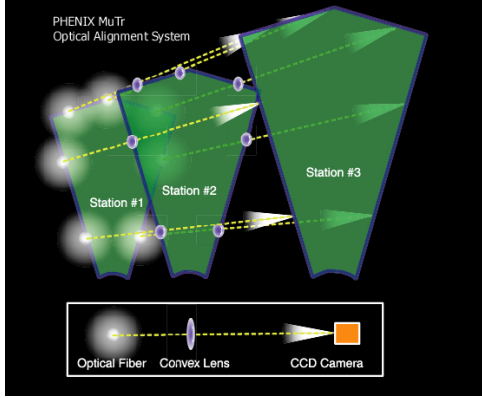


Fig. 5. Optical Alignment System in which light from an optical fiber is projected from station 1 through station 2 to a CCD mounted on station 3. The relative chamber positions are monitored to  $\pm 25$  mm.

stored samples from all channels are digitized and the results are sent to the PHENIX data collection module (DCM).

To meet the design requirement of  $100 \mu\text{m}$  resolution, the rms noise at the input to the preamps was required to be  $0.5 \text{ fC}$  ( $3125 \text{ e}$ ) for a typical pulse of  $80 \text{ fC}$ . This is for a preamp with  $3.5 \text{ mV/fC}$  and a dynamic range of 11 bits.

Space constraints precluded placing the electronics directly on the chambers so  $60 \text{ cm}$  ( $45 \text{ cm}$  for Stn 1) cables connect the front-end electronics to the chambers. The electronics is modular. Two types of 6U size boards are contained in custom chassis. The chassis includes water cooled side plates and a backplane for communication between boards. The Cathode Readout Board includes 64 channels of preamp (8 CPA chips) and two AMUADCs. These two ASICs were designed at ORNL [1]. The performance of the CROC

board is detailed in [2]. The ADC clock is  $200 \text{ MHz}$  so for 11 bit accuracy, 4 samples can be converted within the time constraint of  $40 \text{ micro-sec}$  per event. Up to five events can be converted and stored locally to be transferred to the PHENIX DAQ. The Control board includes the ARCnet interface, the FPGA to control the AMUADCs, and the CLink transmitters and receivers for the GTM and DCM information.

A platform mounted on top of the magnet supports three electronics racks. These contain the high voltage power supplies for the chambers, the low voltage power for all the electronics, interfaces for fiber optics from the PHENIX counting house, calibration electronics, and auxiliary controls and monitoring.

Fast timing signals carried on optical fibers (GLink) are translated to copper wires (CLink) just outside the magnet and transported to the chassis via  $7 \text{ m}$  cables. Similarly, outgoing data packets travel on cables to the CLink/Glink interface and then to the data collection modules in the counting house on optical fibers. A separate system, called ARCnet is used for slow controls information to the chassis and the GLink/CLink crates. Important functions of this system include downloading serial string information to the CPA, AMUADC, and FPGA chips to set operating parameters, the interface to temperature, voltage, and current monitors, and the ability to remotely download the FPGA code.

A calibration system has been imple-

mented to inject pulses to all of the chambers. Data will be analyzed to determine relative gains and to correct for nonlinearities in the electronics.

### 2.3 Integrated Performance

Integrated performance of the production chambers and electronics has been studied in a cosmic-ray test with one station 2 chamber and its full complement of electronics, and in readout of the entire South Muon Tracker system prior to the year 2001 RHIC run. The cosmic-ray test data showed that the system was capable of meeting the noise specifications and that  $100\text{ }\mu\text{m}$  resolution could be achieved with the station 2 chamber. The noise specifications have now been met on the full south muon tracker system and the system has been shown to be robust over several months of data taking. The current readout system is very close to design specifications, capable of doing 4-sample ADC conversions within 50 micro-seconds and holding up to 4 events worth of data in front-end electronic buffers. The goal of the next version of the FPGA program is to meet the PHENIX readout design specifications, i.e., perform ADC conversions within 40 micro-seconds time budget and store up to 5 events in the buffer. The FPGA code can be updated remotely at any time through an ARCnet serial download.

The cosmic-ray test was performed with one station 2 chamber, 960 channels of production front-end

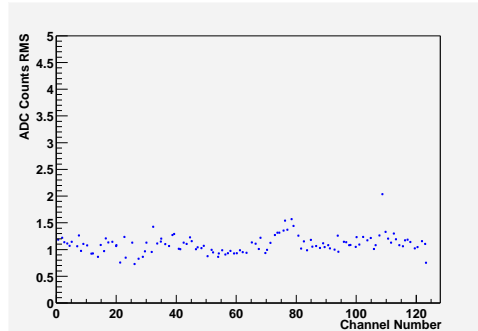


Fig. 6. RMS noise measurement for 128 typical channels in units of ADC counts (1 ADC count  $\sim 2\text{ mV}$ ) obtained in cosmic-ray tests of the Station 2 octant.

electronics, the same high-voltage and low-voltage distribution system that is used in the final system, and with a copy of the PHENIX data acquisition system. The noise specifications of 0.5 fC were met, as can be seen in Fig. 6, where the RMS values of the pedestals on all readout channels are shown.

Two scintillators, one on either side of the station 2 chamber, were used to provide a trigger for cosmic rays going through the chamber. The data collected from this trigger were searched for clusters in each cathode readout plane, the clusters were fit to extract the centroid strip positions, and 5 out of 6 of the readout planes were fit to a straight line and projected to the sixth, central non-stereo readout plane. A cut was placed on the straight line fit to only select tracks which were approximately perpendicular to the face of the chamber and the difference between the projected straight-line fit and the measured position on the sixth plane was plotted. The result is shown in Fig. 7, where a resolution of approximately  $100\text{ }\mu\text{m}$  was achieved

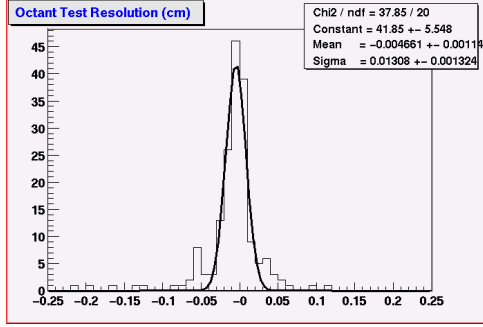


Fig. 7. Measurement of position resolution obtained in cosmic-ray tests of a station 2 octant. The composite chamber plus projection error was about 131  $\mu\text{m}$ , consistent with the 100  $\mu\text{m}$  specification for the chambers and readout alone.

when the projection error is removed from the residual.

The entire South Muon Tracker system was installed in the Muon magnet in the PHENIX Assembly Hall late in the year 2000. The complete installation and shakedown of the FEE system was completed in late January 2001. The entire readout chain from cathodes strips through the data-acquisition system was also studied with the calibration system. Each individual channels' gain, pedestal and variation (or noise) in the pedestal was measured. The dynamic range in the charge measurement of the system was verified and long runs demonstrated the stability of the FEM's optical links. Figure 8 shows results from about one million events collected over a few days during the detector commissioning period.

Monitoring of the electronics temperature is an important issue since the muon front-end electronics will operate inside the closed magnet for

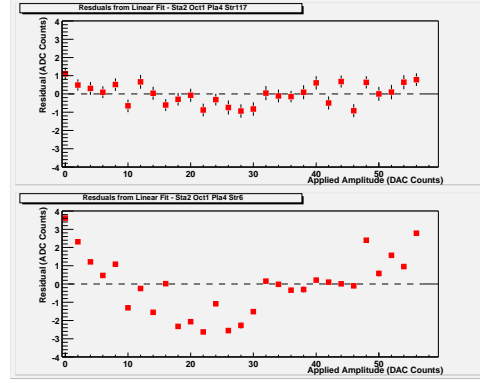


Fig. 8. Test of the dynamic range and stability of the muon tracker spectrometer in a calibration run of one million events.

an extended period of time and some of the electronics components are sensitive to temperature. The slow control system based on the ARC-net protocol has proven to be able to monitor all the crate temperatures. Also the water-cooling system, which can carry away enough heat to keep the electronics in normal operational mode, has been exercised extensively in the assembly hall.

The full array of muon cathode-strip chambers has been tested up to the nominal high voltage (1700 VDC) in place in the magnet. The optical alignment system is fully installed and images are seen on all the cameras. The South magnet has had all lampshade panels installed, and the magnet has been moved into place near the intersection region. The detection of the first  $J/\psi$ 's at RHIC is expected soon after the beam turns on for the year 2001 PHENIX run.

### 3 The Muon Identifier

The irreducible  $\mu/\pi$  ratio due to weak decay inside PHENIX is approximately  $1 \times 10^{-3}$  (primarily determined by the proximity of the nosecone to the vertex). We set a detector design criteria to  $1/4$  of this, namely  $2.5 \times 10^{-4}$ , for a pion from the vertex (or a hadronic descendant) to be misidentified as a muon (forming part of a dimuon). The factor of  $1/4$  provides over an order of magnitude suppression for the *pair* background. Thus, the irreducible background of muons reaching the muon identifier, as opposed to the muon identifier design and the algorithms used to reject the larger hadron background, will set the ultimate physics background level. Of this required net  $\mu/\pi$  separation, approximately  $10^{-2}$  is provided by the presence of the absorber preceding the muon identifier which filters out pions. This leaves 3% as the maximum tolerable fraction of the charged pions which may subsequently be misidentified as muons.

In order to set the punchthrough probability for pions of up to 4 GeV/c to be 3% or less, a total steel depth of 90 cm (5.4 hadronic interaction lengths) is required beyond the nosecone and central magnet. Subtracting the thickness of the muon magnet backplate, a total depth of 60 cm of steel is required in the muon identifier itself. A muon at the vertex must have a mean energy of at least 1.9 GeV to reach the muon identifier system. The mean minimum original energy for a muon to penetrate com-

pletely through the muon identifier is 2.7 GeV.

#### 3.1 Detector Design

Segmentation of the absorber into multiple layers improves the measurement of the trajectory in the identifier. It is desirable to have the early absorber layers be divided more finely to increase the acceptance for  $\phi$  meson detection. The segmentation chosen is a total of four steel absorbers after the 30 cm thick muon magnet backplate of the north arm of thicknesses 10, 10, 20, 20 cm. The 5 gaps created by the absorbers are instrumented with the muon identifier panels. The muon identifier for the south arm is identical to that for the north arm (although the muon magnet backplate is only 20 cm thick) and at the same distance from the interaction vertex.

We use the term Iarocci tubes to refer to planar drift tubes consisting of 100- $\mu$ m gold-coated CuBe anode wires at the center of long channels of a graphite-coated plastic cathode. This same physical detector when operated at higher voltage is a conventional limited streamer tube. We operate them in the proportional mode to increase longevity. They are proportional tubes operated at a voltage such that only a fraction of the signals are not proportional mode pulses.

Iarocci tubes [3] were chosen as the detector technology. They have proven reliability and longevity, com-

pactness, low cost, and are readily available from commercial vendors. Such tubes can be used economically to tile large areas. They have robust wires and seals. They avoid the problems of metal-plastic transitions present at the endcaps for aluminum proportional tubes.

Standard commercially-available Iarocci tubes have a width of 8.5 cm. Beam gas studies show that for low polar angles ( $20^\circ$  or less), an effective segmentation into logical pads of approximately 13 by 13 cm is required to suppress false roads for tracks in the muon identifier. Rather than develop Iarocci tubes of greater width or use 13 cm wide external strips, the most cost effective solution is simply to use standard-width 8.5 cm tubes with all eight internal wires ganged together. This provides a readout pitch of 8.5 cm along both the  $x$  and  $y$  directions, thus providing effective 8.5 cm square hodoscopic cells (upon forming the appropriate ANDs). This most cost effective solution exceeds our requirements. This segmentation is fine enough to provide sufficient granularity for matching roads in the identifier to tracks in the muon tracker unambiguously with anticipated occupancies.

Tubes with 9 mm by 9 mm channels satisfy the count-rate and position localization requirements, but must be staggered by half a cell and ORed in pairs (discussed below) to meet the timing requirements of the Local Level 1 (LVL-1) trigger system. We require a drift time interval shorter than the time between beam collisions (106 ns) minus the flip-flop set-

ting time (25 ns) in order to avoid dead time. At 81 ns, the two-packs are measured to have only a 5% inefficiency when operated with a 9:91 mixture of Isobutane and  $\text{CO}_2$ .

An individual anode wire and the immediately surrounding gas volume and graphite-coated walls are referred to as one channel of an Iarocci tube. There are 8 such wires in a tube. Each wire is held at the center of its channel by means of plastic wire spacers positioned every 50 cm along the tube. A two-pack is a pair of tubes connected together and staggered by half a channel. Their signals are OR'd together. Groups of two-packs oriented both horizontally and vertically are held inside an aluminum box. Approximately half are oriented horizontally and half are oriented vertically so that both projections are measured. This total detector element is called a muon identifier panel. There are six such panels per gap labelled A through F (counterclockwise from the upper left) arranged around the square hole left for the beam pipe to pass through. The large panels A, C, D, F are located at the 4 corners of the gap. Each contains 118 horizontal tubes of length 5200 mm and 128 vertical tubes of length 5010 m. The small panels B and E are situated above and below the square hole, respectively. Each containing 90 horizontal tubes of length 2504 mm and 52 vertical tubes of length 3821 mm. In this way, 1268 tubes per gap (6340 tubes per arm) are distributed to tile an area of 13.1 m wide by 10.7 m high in each gap. Adjacent panels overlap along their edges to eliminate

the creation of any deadspace by the panel frames. Panels (A, C, and E) lie in one plane which is 10 cm closer to the vertex than the plane of the other panels (B, D, and F). The acceptance reaches down to  $10^\circ$  in the first plane (and even farther in subsequent planes) except immediately at the four corners of the square beam hole.

The muon identifier planes need not be surveyed with respect to the vertex to better than approximately  $\pm 4$  mm in the  $x$  and  $y$  directions in order to have alignment errors be negligible compared to multiple scattering errors. It is only required that the  $z$  positions be measured after they are installed, and this measurement only has to be known to within a few centimeters relative to the vertex.

The muon identifier has two separate gas volumes. The primary one is the tube gas volume. The secondary volume is the aluminum enclosure of each panel surrounding the primary volume. A mixture of CO<sub>2</sub> and up to 25% i-C<sub>4</sub>H<sub>10</sub> is fed into the primary volume for chamber operation. N<sub>2</sub> is fed into the secondary volume in order to keep the chamber electronics dry and clean, and to dilute the flammable gas component in the case of a primary volume leak. There are a total of 600 gas circuits for the primary volume. The total sizes of the primary and secondary volumes are 50 m<sup>3</sup> and 40 m<sup>3</sup>, respectively. The gas flow rate of the primary volume is one volume exchange per day. The gas supply system can recirculate up to 50% of the low of primary volume.

### 3.2 Readout

We have chosen to operate the LSTs in proportional mode to ensure maximum longevity. We have selected to operate the tubes at 4500 V with a CO<sub>2</sub> i-C<sub>4</sub>H<sub>10</sub> mixture.

To ensure adequate signal-to-noise performance in the unknown noise environment at RHIC we settled on a readout scheme that employs in-panel amplification (x150) driving differential signals on 30m twisted-pair cables to a crate-based processing system. Here the signals must be digitized and synchronized such that all signals from a beam crossing arrive simultaneously (a significant challenge given the inherent differences in drift-time, transmission time down the 5m LSTs and large slew for near-threshold hits). Data from every crossing is sent as the Muon arm input to the LVL1 trigger. Trigger latency (for all beam crossings) and readback latency (for LVL1-accepted crossings), required to satisfy the PHENIX pipelined/deadtime-less specification, is provided locally.

The anodes from two half-cell staggered LSTs are capacitively coupled into the amplifier circuit, thus comprising a readout channel. In addition to signal amplification, the in-panel portion of the electronics must distribute high voltage to the LSTs. Six readout channels are mounted on a  $8.2 \times 50.4$  cm<sup>2</sup> printed circuit board. Different channels share powered HV buses and a pulser circuit. The amplification circuit and HV distribution circuit are mounted on opposite

sides of the board so that the HV can be isolated from human contact. The boards are mounted inside the panels at the LST endcaps. The primary requirement for the in-panel portion of the electronics was longevity.

The amplification circuit was based on an L3 design[4] with several features incorporated to improve longevity: 1) Resettable polyfuses on the power inputs of each channel, 2) A double-diode protection circuit that allows an amplifier channel to survive even after one of its input LSTs has broken a wire, and 3) Diode clamps to prevent reverse-bias damage. Furthermore, the HV input for each LST has a 400 M $\Omega$  current-limiting resistor so that the HV for the circuit will continue to operate with multiple tube failures and all HV components are encapsulated in a silicone conformal coating to enhance longevity and safety.

In addition to these steps, we have maintained a design in which different LST planes are on independent separate gas and HV circuits and each plane is further segregated into roughly 24-channel HV, gas and power segments.

The out-panel (post-amplifier) electronics are housed in a set of four 9U crates, each of which has the types of cards described below as well as transition cards and a custom backplane.

The FEM cards are analogous to a conventional crate controller, providing the interfaces between the MUID and the PHENIX online systems (with the exception of LVL1).

The timing and control interface receives mode bit information and uses a state machine to parse the instructions, validate them and route them to the appropriate places. Upon receipt of a LVL1-accept signal the DCM interface assembles and ships out the data from all ROCs in the crate.

The ROC cards consist of analog processing and synchronization, buffering, supplemental diagnostics, and serial control. The first stage of the analog processing chain is a differential receiver for the input signals which converts the signals to single-ended and amplifies them by 3. The signals then go through a novel delayless constant-fraction discriminator to eliminate small-signal slew [5]. Synchronization is obtained in stages through a series of programmable delays and multiplexers that allow the operator to select the optimal clock phase for each channel (by delaying the clock and not the channel we can exchange delay lines for multiplexers, greatly reducing the cost of the system). With this scheme we can synchronize all channels if the following two restrictions are met: 1) all signals coming into a ROC must arrive within one RHIC cycle (106 ns), and 2) the earliest signals into all ROCs must arrive within one RHIC cycle.

### *3.3 Level-1 Trigger*

The muon identifier 96 bits of data from each ROC to the LVL1 trigger system (discussed elsewhere in this volume) where an algorithm is im-

Table 1. The performance of the muon identifier

Momentum GeV/c	Overall Muon Efficiency (%)	Pion Rejection Rate
2.0	$65.3 \pm 1.1$	$(2.0 \pm 1.4) \times 10^{-3}$
3.0	$93.7 \pm 1.4$	$(2.3 \pm 0.5) \times 10^{-3}$
4.0	$96.9 \pm 1.4$	$(2.5 \pm 0.5) \times 10^{-3}$
5.0	$98.1 \pm 1.4$	$(3.7 \pm 0.6) \times 10^{-3}$
10.0	$99.6 \pm 1.4$	$(3.9 \pm 0.7) \times 10^{-3}$

plemented to determine if there are candidate muon tracks in the event. The algorithm finds roads allowing missed gaps, is steerable from gap to gap based on the hit pattern in the two preceding gaps, has a programmable depth, and phrases its requirements in terms of the number of deep or shallow roads in each orientation. The LVL-1 trigger efficiency is flat as a function of rapidity over almost the entire acceptance.

### 3.4 Detector Performance

Single-muon events were simulated and reconstructed to check the reconstruction efficiency of the muon identifier; single-pion events were simulated to see the hadron rejection capability as well. The performance of the muon identifier in high multiplicity was also investigated by mixing  $J/\Psi$  signal events with central Au-Au background events.

The results shown in Table 1 indicate an overall muon efficiency of about 65-99% in 2.0-10.0 GeV/c momentum region, and a pion rejection rate of about  $2.0 \times 10^{-4} - 3.9 \times 10^{-3}$  in the

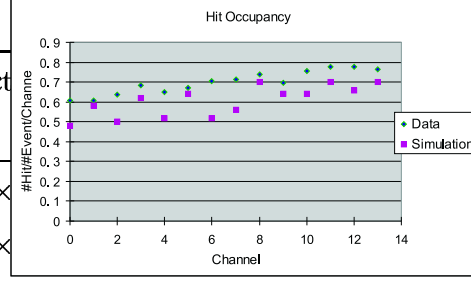


Fig. 9. Channel occupancy.

same momentum region. The lower efficiency at 2.0 GeV/c is due to the energy loss caused by central magnet and muon identifier absorber. The pion rejection rate is close to the pion decay probability, especially for momentum below 5.0 GeV/c. The numbers in Table 1 are consistent to the result from our test experiment in KEK with 1.5-4.0 GeV/c pion/muon beam.

In the summer of 2000, the PHENIX muon identifier was partially instrumented and operated with pure CO<sub>2</sub>. The good agreement between number of charged particles in BBC and hit multiplicity in muon identifier indicates that the real gold-gold collision has been seen by the muon identifier. Fig. 9 shows the occupancy per channel for data collected using 10 channels of the muon identifier (in an early engineering run) compared to the expected occupancy based on simulations.

## 4 Acknowledgements

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